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# THE EFFECT OF FERTILIZERS ON THE SULPHUR CONTENT OF SOIL AND CROP PLANTS

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University of Alberta

April, 1942

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# THE EFFECT OF FERTILIZERS ON THE SULPHUR CONTENT OF SOIL AND CROP PLANTS

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Department of Soils

A THESIS

submitted to the University of Alberta in partial
fulfilment of the requirements for the degree of
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# THE EFFECT OF FERTILIZERS ON THE SULPHUR CONTENT OF SOIL AND CROP PLANTS

## INTRODUCTION

The object of the work reported in this thesis was to determine the effect, if any, of the various fertilizers on the sulphur content of the cereals and legumes grown on the gray wooded soils at Breton and the black soil at Edmonton; also on the gray wooded soil itself.

Sulphur is an essential constituent of most of the proteins found in plants. Therefore if there is not enough available sulphur in the soil the plants are certain to be affected adversely. This is much more noticeable in plants of high sulphur requirement such as legumes and plants which belong to the Cruiciferae family. In fact, it is the sulphur compounds which give cabbage and cauliflower their characteristic taste and odor.

Sulphur fertilizers have long been used on this continent and in western Europe, but it was not until the middle of the last century that sulphur became recognized as an indispensable plant nutrient. Until very recently it has been thought unnecessary to apply sulphur or sulphur compounds as a fertilizer.

Fertilizers are applied to the soil mainly to increase

yields, but they also have a definite effect on the composition of the plant. Until recently, the increase in yields has generally been attributed to nitrogen, phosphorus and potassium, but recent work has shown that on many soils sulphur has a far greater effect than was formerly supposed. The problem of maintaining a balanced supply of plant nutrients in the soil is frequently aggravated by the application of one or two elements because this often causes an increased assimilation of other elements not supplied in the fertilizer. Furthermore, as plants and their products are valued for the constituents which they contain, any factors such as the application of fertilizers or soil variations which may affect directly or indirectly the composition of the plant are worthy of consideration.

Soils of the black and brown soil zones of Alberta are relatively well supplied with sulphur in the surface layers and often abundantly in the lower layers (29). The gray wooded soils are lacking in sulphur and this is probably due to their lower organic matter content and to the fact that they have been badly leached. In the brown soils, especially, the zone of sulphate concentration is quite near the surface whereas in the black it is deeper and in the gray wooded is commonly still deeper and less distinct. Thus an inverse relationship can be established between the leaching and rainfall on one hand and the concentration of the sulphates on the other.

## REVIEW OF LITERATURE

On the basis of early ash analyses by Wolff (25), the sulphur content and requirement of crops was considered to be very low. It was not until the improved method of sodium peroxide fusion and other methods used by Hart and Peterson, and Shedd (5, 21) were developed that the sulphur content of plants was found to be higher than formerly supposed.

Alway, Olson and St. John, Powers, and Reimer and Tartar (1, 13, 15, 17) found that alfalfa grown on sulphur treated plots contained a higher percentage of sulphur than alfalfa grown or untreated sulphur deficient plots; also that the sulphur increased the protein content of crops.

Woodford and McCalla (26) indicated that nitrogen and sulphur were limiting the growth of wheat on the gray soil. They suggest that the proportionately high absorption of phosphorus from the soil was in compensation for the low availability of nitrogen and sulphur.

Brown and Kellogg, Hart and Peterson, and Shedd (4, 5, 21) show that many cultivated plants contain more sulphur than phosphorus.

Brown and Kellogg (4) showed that Iowa soils contain small amounts of total sulphur--much less than the average phosphorus content of the large soil areas. Shedd (21) states that the Kentucky soil areas contain less sulphur than phosphorus. Powers (15) states that the basaltic areas in northwest Oregon contain relatively small amounts of sulphur.

Robinson's analyses (18) of different types of soil from various regions showed an extreme variation of 160 pounds to 2600 pounds of sulphur per acre in the surface soil. Wyatt and Doughty (29) state that the variation in the sulphur of the non-alkali mineral soils of Alberta is from 320 to 710 p.p.m. in the surface soil whereas the phosphorus varies from 380 to 1250 p.p.m. The sulphur content of the gray wooded soils of Alberta is lower than that of the brown and black soils (11, 28, 29, 30, 31).

Hart and Peterson (5) calculated from Rothamsted data that the amount of sulphur lost by drainage is three times the amount brought down in rainfall.

Hart and Peterson (5) place the annual amount of sulphur precipitated with the rain at Wisconsin around 7 pounds per acre. Powers (15) of Oregon states that only a few pounds can be expected. Stewart (22) reports that 45.1 pounds were received in precipitation at the Illinois station, while MacIntire (10) found that 49.6 pounds of sulphur an acre were added by precipitation at Knoxville, Tennessee. Alway (2) of Minnesota states that only 4 to 5 pounds of sulphur per acre are precipitated with the rain in districts remote from coal burning towns, whereas the amount of sulphur increases in proximity to these towns.

Alway, Hart and Peterson, Newton, Wyatt and Newton, Powers, Reimer and Tartar (1, 5, 11, 28, 15, 17) found increases in yield when sulphur fertilizers were applied to soils deficient in sulphur. It has frequently been observed that if wheat

or another cereal follows a good crop of clover and is fertilized with ammonium sulphate or ammonium phosphate (containing sulphate) or certain other fertilizers, the grain yield is increased far more by the combination of fertilizer and clover than by the fertilizer alone (11, 27, 28, 29, 30).

Brown and Kellogg (4) found that soils have a definite sulphofying power which is mainly due to bacterial action. Younge (31) found that the higher the organic matter content the greater the sulphofying powers, the black soil of Alberta having a much greater sulphofying power than the gray wooded soil. Lipman (8, 9) has shown that the oxidation of sulphur in composts will increase the solubility of phosphorus in rock phosphate. Hart and Tottingham, Lipman, Newton, Powers, Pitz, Rountree, and Younge (6, 8 & 9, 12, 15, 14, 19, 31) all recorded an increase in acidity only when large amounts of sulphur were applied to overcome the buffering capacity of the soils used in their work.

Sulphur in the form of gypsum has been used quite successfully for the reclamation of black alkali (20). Base exchange takes place between the black alkali and the gypsum, resulting in increased permeability of the soil due to flocculation which facilitates the removal of the sodium salts by leaching. Powers and Thomas (16, 24) found that large quantities of gypsum were needed to give the desired results while smaller quantities of elemental sulphur accomplished the same purpose.

## MATERIAL

The material analyzed has been collected by the Department of Soils, University of Alberta, in connection with the fertilizer work carried on by the department on the gray wooded soil experimental plots at Breton and the Soils Experimental Farm at the University. The application of the fertilizers and the harvesting of the crops were carried out by the department.

### Description of the Breton Experimental Field

Series A, B, C, D, and F, plots 1 - 11, consist of a rotation as follows: (1) barley and clover, (2) clover, (3) clover, (4) wheat, (5) oats.

Series E, plots 1 - 11, is a continuous wheat series, but because of weeds it was fallowed in 1932 and 1938. The west half of this series was in wheat in 1941 and the east half was fallowed.

Series F was under alfalfa before 1939 and was plowed and seeded to wheat in 1939. Prior to 1939 a four-year rotation was followed and series F was not included in the rotation. Series G grew flax in 1937, barley and Altaswede in 1938, Altaswede in 1939, Altaswede in 1940 and 1941.

The recent crop history of these series is shown in Table 1.

Table 1. Crop rotations used on Breton experimental field, 1936-41

| Series | Plots | 1936 | 1937 | 1938 | 1939 | 1940 | 1941 |
|---|---|---|---|---|---|---|---|
| A | 1-11 | Oats | Barley with clovers | Clovers | Clovers | Wheat | Oats |
| B | 1-11 | Wheat | Oats | Barley with clovers | Clovers | Clovers | Wheat |
| C | 1-11 | Clovers | Wheat | Oats | Barley with clovers | Clovers | Clovers |
| D | 1-11 | Barley with clovers | Clovers | Wheat | Oats | Barley with clovers | Clovers |
| E | 1-11 | Wheat | Fallow | Fallow | Wheat | Wheat | Wheat |
| F | 1-11 | Alfalfa | Alfalfa | Alfalfa | Wheat | Oats | Barley |
| G | 1-11 | Clovers and timothy | Flax | Barley with clovers | Clovers | Clovers | Red clover |

Series A to G each contain plots fertilized yearly except where special mention of years fertilized is made. The rates of application are as follows:

| | | |
|---|---|---|
| Plot | 1 | Check. |
| " | 2 | Manure, 22 tons per acre (1930, 1932, 1936, 1938). |
| " | 3 | Complete fertilizer; 66 lb. ammonium phosphate (16-20), 33 lb. $K_2SO_4$ per acre. |
| " | 4 | Ammonium sulphate, 80 lb. per acre. |
| " | 5 | Check. |
| " | 6 | Lime (marl), 1 ton per acre (every 4 years). |
| " | 7 | Lime (marl), 1 ton (every 4 years) and triple super, 67 lb. per acre. |
| " | 8 | Triple super, 67 lb. per acre. |
| " | 9 | Manure, 22 tons (1930, 1932, 1936, 1938) and triple super, 55 lb. per acre per year up to 1938 inclusive; in 1939 and later ammonium phosphate (16-20), 67 lb. per acre. |
| " | 10 | Ammonium phosphate (16-20), 65 lb. per acre. |
| " | 11 | Check. |

## Description of the Soils Experimental Farm at the University

The soil was first broken in 1923, cropped without fertilizers until 1931, and fertilized since 1931. The rotation is two years clover and three years grain, and consists of five series so that each crop is grown each year. The check plots are replicated six times and each fertilizer is replicated three times. The fertilizers used are ammonium sulphate, ammonium phosphate (11-48), triple superphosphate, and complete.

# METHODS OF SULPHUR ANALYSIS

## Magnesium Nitrate Method for Plants (3)

Weigh one gram of material into a large porcelain or sillimanite crucible. Add 7.5 cc. of $Mg(NO_3)_2$ solution, taking care that all the material is brought in contact with the solution, and heat on an electric hotplate (180°) until no further reaction takes place. Transfer the crucible to an electric muffle and allow it to remain at low heat (muffle must not show any red) until the charge is thoroughly oxidized. It may be necessary to remove from muffle, moisten with $H_2O$ and add some $Mg(NO_3)_2$ solution, evaporate and return to the muffle. Remove crucible from muffle and cool. Add $H_2O$, then HCl in excess. Bring the solution to a boil, filter, and wash thoroughly.

Dilute the entire filtered solution to 200 cc., add HCl to make approximately 0.5 cc. of free acid present. Heat to boiling and add 10% $BaCl_2$ solution slowly with constant stirring. Continue boiling for five minutes and allow to stand for five hours or longer in a warm place. Decant the liquid through a previously weighed Gooch crucible, wash with hot water until free from chlorides. Dry the Gooch and weigh as barium sulphate. Multiply the result by the factor 0.1376 and report as percentage of sulphur.

## Magnesium Nitrate Method for Soil (23)

Moisten 5 grams of the soil sample with a little alcohol in a porcelain dish and add 10 cc. of the magnesium nitrate

solution. Mix sample and $Mg(NO_3)_2$ solution well, evaporate to dryness and char on an electric hotplate until no further action takes place. Place a watch glass over the dish just as charring commences. Ignite in an electric furnace at 600°C. until the charge is thoroughly oxidized. No black particles should remain. Add enough water to moisten. Add 10 cc. of concentrated HCl and evaporate to dryness. Moisten with water and add 10 cc. of concentrated HCl, heat to boiling, filter and wash on Buchner funnel into a filter flask, using medium suction (No. 3 Whatman filter). Transfer the filtrate into a 250 cc. beaker. Heat the filtrate to the boiling point, add drop by drop 5 cc. of a 10% solution of $BaCl_2$. Digest one to two hours on a low heat hotplate, allow to stand overnight or an equivalent length of time. Filter through a Gooch crucible, dry and weigh as $BaSO_4$. Blank determinations must be made on all reagents used.

Reagents: $Mg(NO_3)_2$ - Dissolve 320 grams of C.P. low sulphur calcined magnesia in 1:1 nitric acid. The magnesia (MgO) must be in excess. Boil, filter and dilute to 2000 cc.

10% $BaCl_2$ solution.

All the analyses were carried out on air-dry material, both plant and soil.

## EXPERIMENTAL RESULTS

Table 2 and Fig. 1 show the sulphur content and yield of wheat grown continuously at Breton. The percent sulphur for the three years' samples analyzed shows a definite increase with the application of sulphur fertilizers. The yield also increases with application of sulphur fertilizers.

Table 3 and Fig. 1 give the yield and sulphur content of wheat grown on the wooded soil after clovers. Here also the percent sulphur increases and so does the yield with the application of sulphur fertilizers.

The greater increases in sulphur content in both these series are found in the wheat receiving ammonium phosphate (16-20) plus potassium sulphate, ammonium sulphate, manure plus ammonium phosphate (16-20) and ammonium phosphate (16-20). These are the fertilizers containing the larger amounts of sulphur as shown in Table 7.

Table 4 and Fig. 1 compare the average yield of continuous wheat and wheat after clover for the years 1939, 1940 and 1941, with the average yield from 1930-1940. It also gives the average sulphur content of the continuous wheat and wheat after clovers for the years 1939-41 inclusive. It will be noticed that the average yield of wheat after clovers is higher than the average yield of continuous wheat for the years 1930-1940. The average yield of wheat after clovers is lower than the average yield for continuous wheat for the years 1939 to 1941. This is because the continuous wheat for

Table 2. The sulphur content and yield of wheat grown on Breton fertilizer plots continuous wheat series

| Plot | Treatment | *Av. yield 1930-40 | Av. incr. | Series E, 1939 |  |  | Series E, 1940 |  |  | Series E, 1941 |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | Yield | Incr. | % S | Yield | Incr. | % S | Yield | Incr. | % S |
| 1 | None | 10.8 | ---- | 32.7 | ---- | .110 | 11.1 | ---- | .110 | 27.3 | ---- | .095 |
| 2 | Manure | 14.8 | 3.7 | 47.4 | 13.6 | .132 | 23.4 | 12.2 | .125 | 50.3 | 23.9 | .139 |
| 3 | Complete | 16.2 | 4.8 | 44.0 | 9.1 | .155 | 14.3 | 3.1 | .139 | 34.0 | 8.5 | .146 |
| 4 | Ammon. sulphate | 16.6 | 4.9 | 42.8 | 6.8 | .168 | 18.3 | 7.1 | .146 | 34.0 | 9.4 | .137 |
| 5 | None | 12.0 | ---- | 37.2 | ---- | .133 | 11.3 | ---- | .101 | 23.8 | ---- | .122 |
| 6 | Lime | 13.1 | 0.8 | 40.9 | 3.1 | .148 | 13.6 | 1.8 | .122 | 26.9 | 1.6 | .129 |
| 7 | Lime + triple | 14.0 | 1.3 | 41.6 | 3.1 | .118 | 15.0 | 2.7 | .114 | 31.8 | 4.9 | .117 |
| 8 | Triple | 12.6 | -0.4 | 41.4 | 2.3 | .144 | 11.8 | -1.0 | .143 | 33.3 | 4.9 | .091 |
| 9 | Manure + phosphate | 18.6 | 5.2 | 53.9 | 14.1 | .142 | 32.8 | 19.5 | .124 | 53.5 | 23.5 | .115 |
| 10 | 16-20 | 16.8 | 3.1 | 48.8 | 8.4 | .177 | 16.1 | 2.3 | .133 | 45.7 | 14.2 | .132 |
| 11 | None | 14.1 | ---- | 41.1 | ---- | .133 | 14.2 | ---- | .113 | 33.1 | ---- | .102 |

*Continuous crops--8 in 11 years.

Table 3. The sulphur content and yield of wheat grown on Breton fertilizer plots after clovers

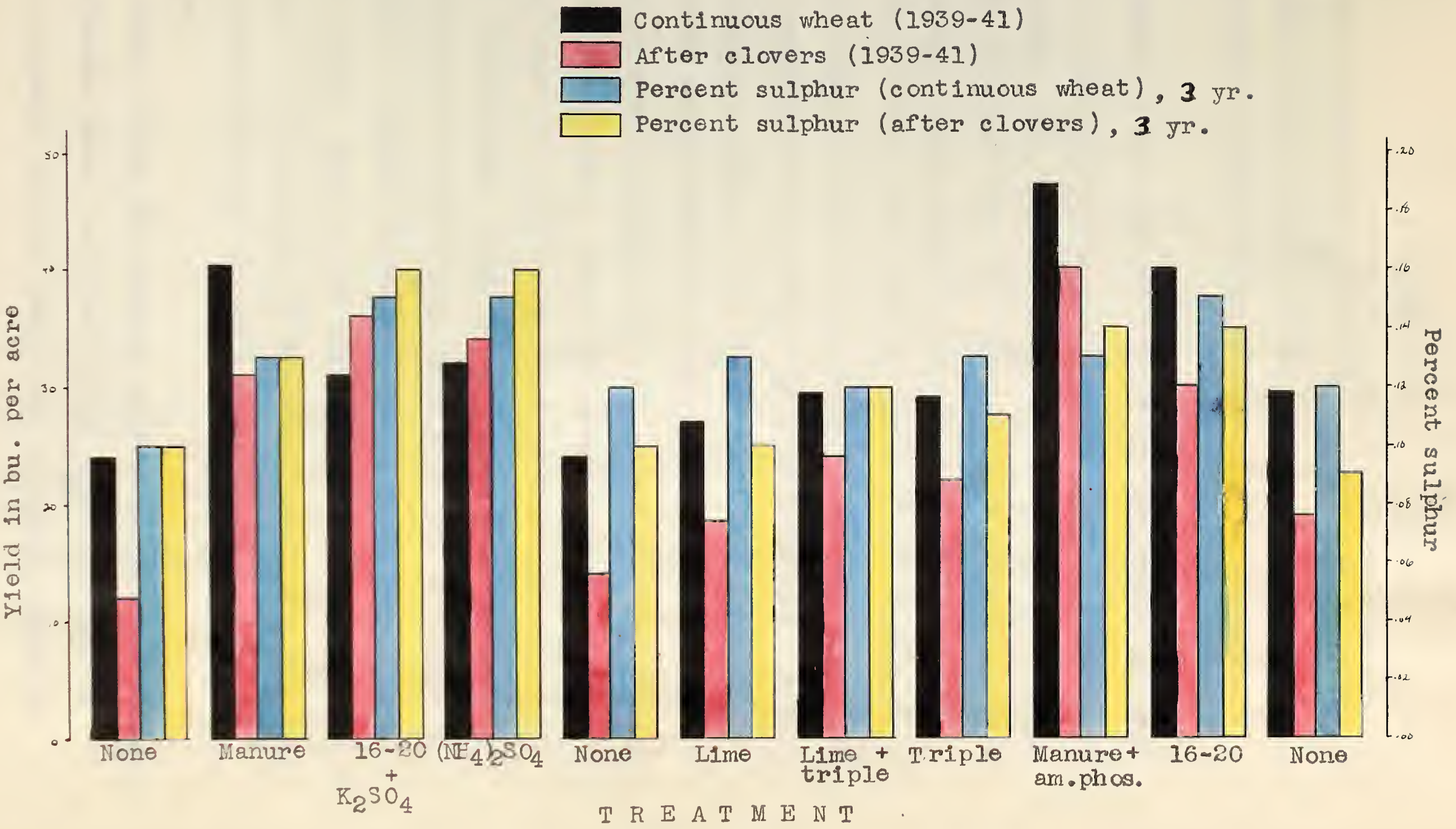
| Plot | Treatment | Av. yield 1930-40 | Av. incr. | Series F West half, 1939 Yield | Series F West half, 1939 Incr. | Series F West half, 1939 % S | Series A East half, 1940 Yield | Series A East half, 1940 Incr. | Series A East half, 1940 % S | Series B East half, 1941 Yield | Series B East half, 1941 Incr. | Series B East half, 1941 % S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | None | 12.8 | ---- | 17.1 | ---- | .132 | 10.8 | ---- | .078 | 9.1 | ---- | .102 |
| 2 | Manure | 23.9 | 10.8 | 42.4 | 24.3 | .146 | 30.0 | 19.7 | .139 | 20.8 | 10.7 | .118 |
| 3 | Complete | 33.5 | 20.1 | 44.1 | 25.0 | .179 | 39.3 | 29.6 | .150 | 24.7 | 13.6 | .146 |
| 4 | Ammon. sulphate | 28.2 | 14.6 | 46.8 | 26.7 | .183 | 30.4 | 21.3 | .159 | 25.7 | 13.6 | .144 |
| 5 | None | 13.9 | ---- | 21.1 | ---- | *--- | 8.5 | ---- | .118 | 13.2 | ---- | .093 |
| 6 | Lime | 17.7 | 3.2 | 27.9 | 5.5 | .117 | 13.6 | 4.1 | .110 | 14.2 | 1.1 | .089 |
| 7 | Lime + triple | 23.4 | 8.3 | 32.2 | 8.5 | .133 | 20.4 | 9.8 | .128 | 19.9 | 6.9 | .095 |
| 8 | Triple | 20.8 | 5.1 | 29.5 | 4.5 | .124 | 17.5 | 5.9 | .111 | 19.2 | 6.3 | .088 |
| 9 | Manure + phosphate | 32.1 | 15.8 | 55.5 | 29.2 | .143 | 34.1 | 21.4 | .157 | 29.5 | 16.7 | .124 |
| 10 | 16-20 | 31.7 | 14.9 | 38.4 | 10.8 | .158 | 30.2 | 16.5 | .142 | 21.4 | 8.7 | .125 |
| 11 | None | 17.4 | ---- | 28.9 | ---- | .096 | 14.8 | ---- | .113 | 12.6 | ---- | .069 |

*Sample destroyed by weevils.

Table 4. The average yield in bushels for 1930-41 of continuous wheat and wheat after clovers compared with the average yield in bushels, and percent sulphur content of continuous wheat and wheat after clovers for 1939-41

| | | Cont. wheat 1930-40 | | Wheat after clovers 1930-40 | | Continuous wheat 1939-41 | | | Wheat after clovers 1939-41 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot | Treatment | Av. yield | Av. incr. | Av. yield | Av. incr. | Av. yield | Av. incr. | % S | Av. yield | Av. incr. | % S |
| 1 | None | 10.8 | ---- | 12.8 | ---- | 23.7 | ---- | .105 | 12.3 | ---- | .104 |
| 2 | Manure | 14.8 | 3.7 | 23.9 | 10.8 | 40.4 | 16.6 | .132 | 31.1 | 18.2 | .134 |
| 3 | Complete | 16.2 | 4.8 | 33.5 | 20.1 | 30.8 | 6.9 | .147 | 36.0 | 22.7 | .158 |
| 4 | Ammon. sulphate | 16.6 | 4.9 | 28.2 | 14.6 | 31.7 | 7.8 | .150 | 34.3 | 20.5 | .162 |
| 5 | None | 12.0 | ---- | 13.9 | ---- | 24.1 | ---- | .119 | 14.3 | ---- | .105 |
| 6 | Lime | 13.1 | 0.8 | 17.7 | 3.2 | 27.1 | 2.2 | .133 | 18.6 | 3.6 | .105 |
| 7 | Lime + triple | 14.0 | 1.3 | 23.4 | 8.3 | 29.5 | 3.6 | .116 | 24.2 | 8.4 | .119 |
| 8 | Triple | 12.6 | -0.4 | 20.8 | 5.1 | 28.8 | 2.1 | .126 | 22.1 | 5.6 | .108 |
| 9 | Manure + phosphate | 18.6 | 5.2 | 32.1 | 15.8 | 46.7 | 19.0 | .127 | 39.7 | 22.4 | .141 |
| 10 | 16-20 | 16.8 | 3.1 | 31.7 | 14.9 | 36.9 | 8.3 | .147 | 30.0 | 12.0 | .142 |
| 11 | None | 14.1 | ---- | 17.4 | ---- | 29.5 | ---- | .116 | 18.8 | ---- | .093 |

Fig. 1. Average yield of wheat grown continuously and after clovers, and percent sulphur (1939-41)



1939 and 1941 follows fallow with the resulting high yields.

The protein content of the grain after clovers is higher than that of wheat grown continuously as shown by Table 5.

There is not much difference in the percent sulphur content of the continuous wheat and wheat after clovers for the years 1939-1941. The continuous wheat (with a higher average yield) contains almost the same percentage of sulphur as does the wheat after clovers (with a lower average yield).

Fig. 1 represents Table 4 graphically. The yield and percent sulphur content of continuous wheat and wheat after clovers is compared for the years 1939, 1940 and 1941. Fig. 2 shows the average yields of continuous wheat and wheat after clovers for the years 1930-1940. The average yield of the wheat after clovers is higher for this period of years than that of the continuous wheat. Also, the greater increases in yield for both of these two series are found in those plots receiving sulphur fertilizers. Thus it is evident that the application of fertilizers together with the inclusion of legumes in a rotation gives a greater increase in wheat yield than do the fertilizers alone. This is not borne out for the years 1939-41 as illustrated in Fig. 1, but as explained previously, the wheat followed fallow in two out of three years in the continuous wheat series.

Table 6 shows the average percent sulphur and nitrogen of the continuous wheat, and wheat after clovers series at Breton for the years 1939 to 1941. The nitrogen content of

Fig. 2. Average wheat yields, Breton, 1930-40

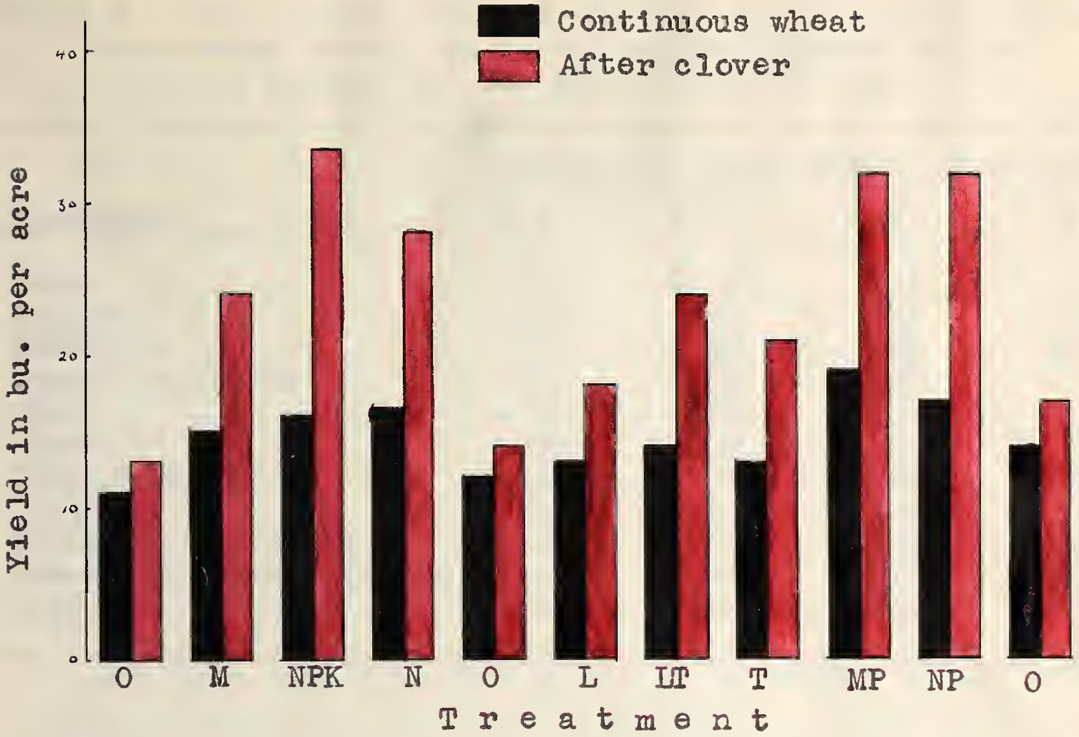


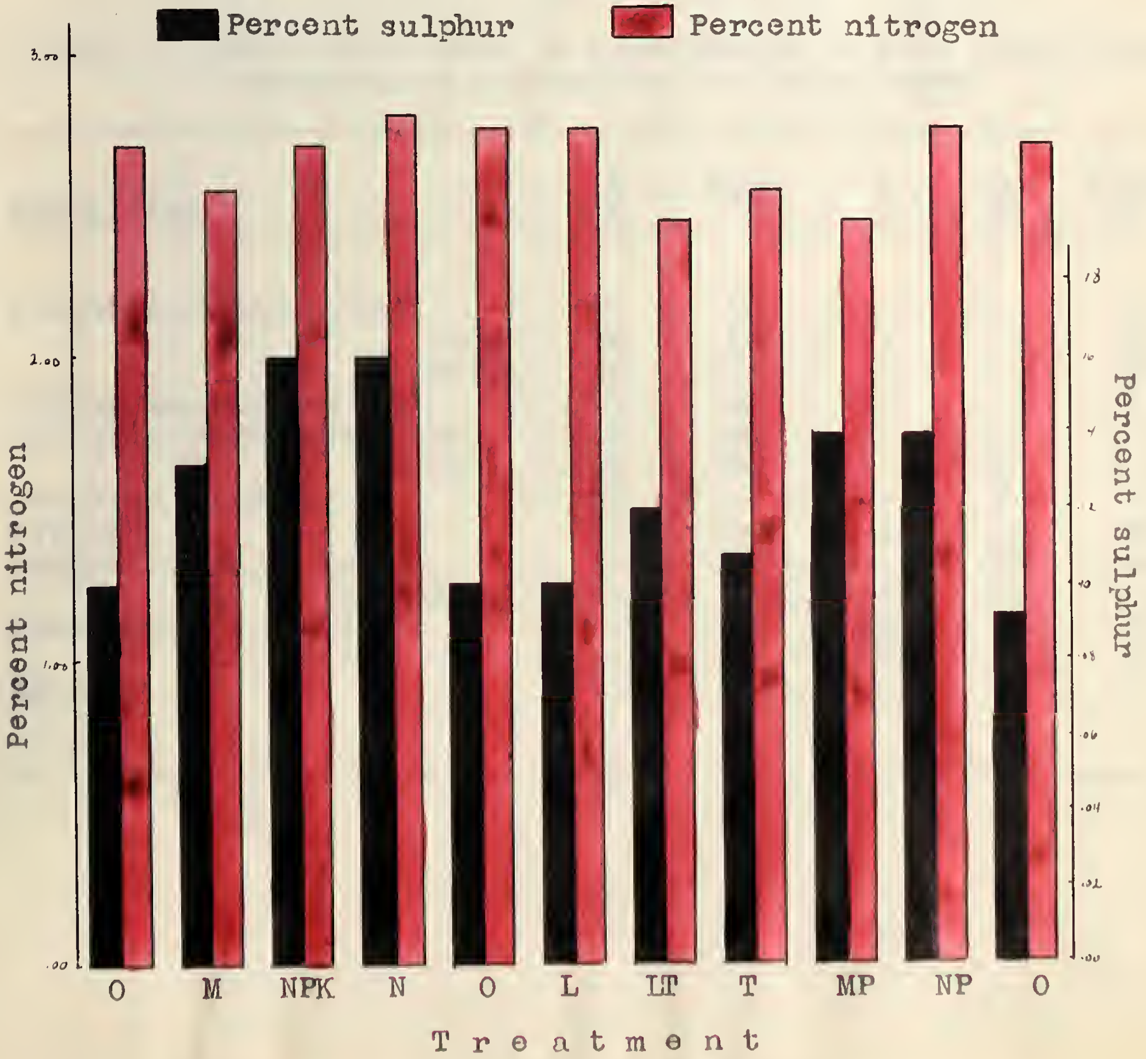
Table 5. Average protein content of wheat at Breton grown after clovers 1939-41, and continuous wheat 1939-41: Reward 1939 & 1940, Thatcher 1941

| Plot | Treatment | Protein % Continuous wheat | Protein % Wheat after clovers |
|---|---|---|---|
| 1,5,11 | None | 10.2 | 14.0 |
| 2 | Manure | 10.2 | 13.2 |
| 3 | Complete | 9.9 | 13.8 |
| 4 | Ammon. sulphate | 10.8 | 14.5 |
| 6 | Lime | 10.0 | 14.0 |
| 7 | Lime + triple | 9.5 | 12.6 |
| 8 | Triple super | 9.6 | 13.1 |
| 9 | Manure + phosphate | 11.8 | 12.7 |
| 10 | Ammon. phosphate (16-20) | 10.7 | 14.1 |

Table 6. The average percent sulphur and nitrogen for the continuous wheat, and wheat after clovers series at Breton for the years 1939 to 1941

| Plot | Treatment | Continuous wheat % S | Continuous wheat % N | Wheat after clovers % S | Wheat after clovers % N |
|---|---|---|---|---|---|
| 1 | None | .105 | 1.89 | .104 | 2.68 |
| 2 | Manure | .132 | 1.98 | .134 | 2.56 |
| 3 | Complete | .147 | 1.92 | .158 | 2.68 |
| 4 | Ammon. sulphate | .150 | 2.10 | .162 | 2.81 |
| 5 | None | .119 | 2.03 | .105 | 2.77 |
| 6 | Lime | .133 | 1.94 | .105 | 2.73 |
| 7 | Lime + triple | .116 | 1.84 | .119 | 2.45 |
| 8 | Triple | .126 | 1.87 | .108 | 2.54 |
| 9 | Manure + phosphate | .127 | 2.28 | .141 | 2.46 |
| 10 | Ammon. phosphate (16-20) | .147 | 2.09 | .142 | 2.74 |
| 11 | None | .116 | 2.04 | .093 | 2.70 |

Fig. 3. The average percent sulphur and nitrogen for the wheat after clovers, 1939-1941



the wheat after clovers is greater than that of the continuous wheat. There is not much difference in the sulphur content between the two series. There does not appear to be any correlation between the application of nitrogen fertilizer and the nitrogen content although the ammonium sulphate plots contain higher amounts of sulphur on the average. The sulphur content increases with the application of sulphur fertilizers but there does not appear to be any increased assimilation of nitrogen with the increased assimilation of sulphur.

Fig. 3 depicts graphically the average percent nitrogen and sulphur of wheat after clovers for the years 1939-1941.

Table 7. Fertilizers used in experiments on gray wooded soils.
Approximate composition of fertilizers.

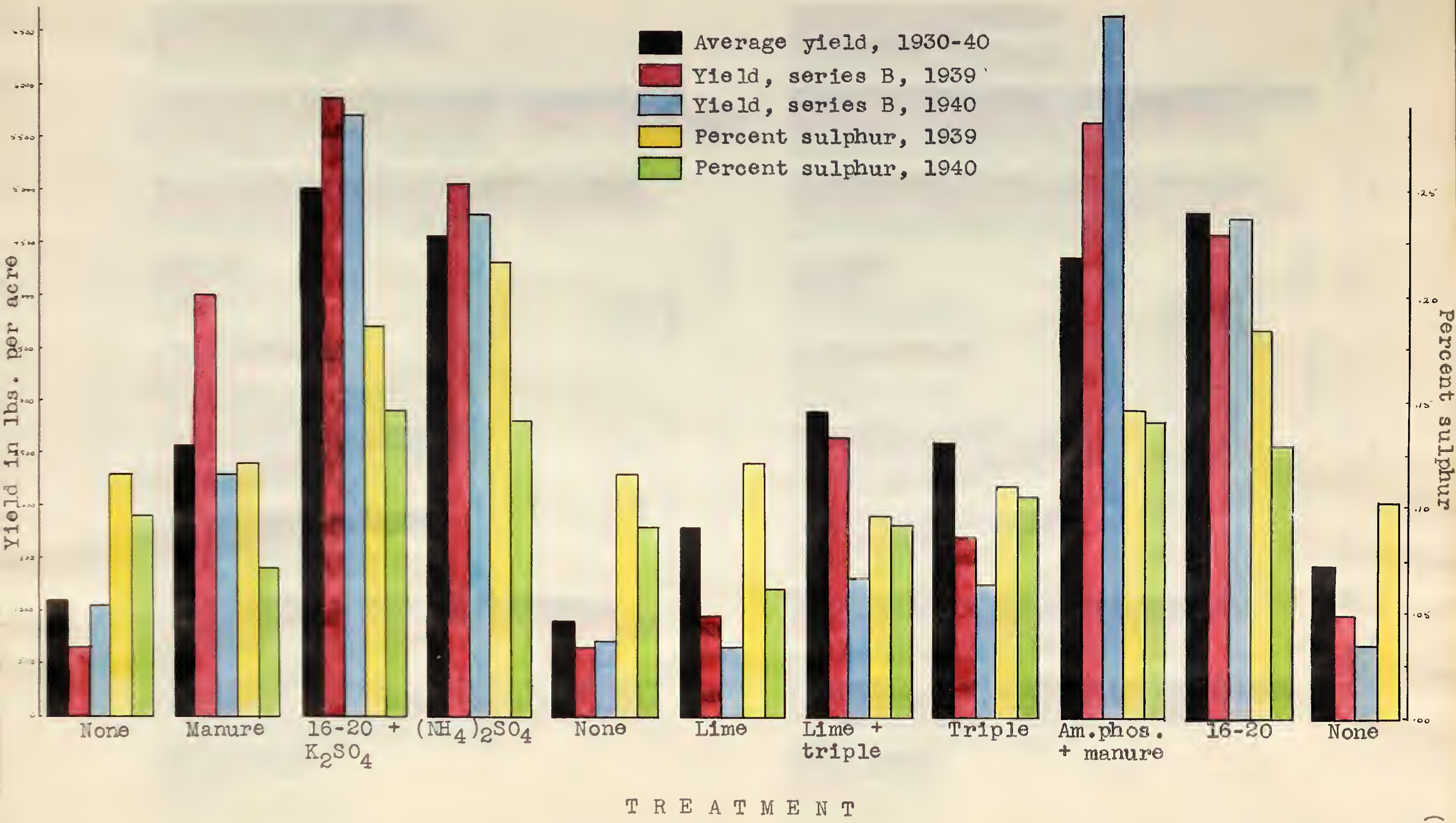
| Fertilizer | N % | $P_2O_5$ % | K % | S % | Gypsum % |
|---|---|---|---|---|---|
| Single superphosphate | -- | 16 | -- | 9 | 50 |
| " " 2-19 | 2 | 19 | -- | 9 | 50 |
| " " 4-15 | 4 | 15 | -- | 9 | 50 |
| Triple superphosphate | 1 | 43 | -- | 1 | 6 |
| Ammonium phosphate 11-48 | 11 | 48 | -- | 2 | -- |
| " " 16-20 | 16 | 20 | -- | 14 | -- |
| Ammonium sulphate | 20 | -- | -- | 24 | -- |
| Gypsum | -- | -- | -- | 18 | 95 |
| Sodium sulphate (dry) | -- | -- | -- | 22 | -- |
| " " (hydrated) | -- | -- | -- | 11 | -- |
| Potassium sulphate | -- | -- | 40 | 16 | -- |
| " chloride | -- | -- | 42 | 1 | -- |
| Sulphur | -- | -- | -- | 98 | -- |

Table 8. The sulphur content and yields of clovers grown on the Breton fertilizer plots*

| Plot | Treatment | Av. yield 1930-40 | Av. incr. | Series A, 1939 |  |  | Series B, 1939 |  |  | Series G, 1939 |  |  | Series B, 1940 |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | Yield | Incr. | % S | Yield | Incr. | % S | Yield | Incr. | % S | Yield | Incr. | % S |
| 1 | None | 1075 | ---- | 646 | ---- | .109 | 673 | ---- | .117 | ---- | ---- | ---- | 1068 | ---- | .096 |
| 2 | Manure | 2546 | 1499 | 2705 | 2107 | .089 | 4000 | 3337 | .122 | 1650 | 945 | 103 | 2328 | 1353 | .071 |
| 3 | Complete | 5018 | 4000 | 5583 | 5033 | .156 | 5855 | 5203 | .187 | 4446 | 3741 | .155 | 5684 | 4799 | .144 |
| 4 | Ammon. sulphate | 4564 | 3565 | 4758 | 4256 | .158 | 5070 | 4428 | .215 | 4929 | 4224 | .158 | 4766 | 3971 | .142 |
| 5 | None | 960 | ---- | 454 | ---- | .082 | .630 | ---- | .115 | 705 | ---- | .092 | 705 | ---- | .092 |
| 6 | Lime | 1809 | 768 | 1012 | 523 | .116 | 937 | 247 | .120 | 587 | -.121 | .082 | 646 | -86 | .059 |
| 7 | Lime + triple | 2891 | 1769 | 1527 | 1003 | .094 | 2654 | 1904 | .095 | 1885 | 1175 | .124 | 1319 | 560 | .091 |
| 8 | Triple | 2616 | 1413 | 1682 | 1122 | .107 | 1677 | 867 | .113 | 1695 | 982 | .085 | 1255 | 469 | .105 |
| 9 | Manure + phosphate | 4355 | 3071 | 4750 | 4154 | .116 | 5655 | 4782 | .147 | 3706 | 2991 | .158 | 6146 | 5333 | .143 |
| 10 | 16-20 | 4791 | 3426 | 4800 | 4187 | .160 | 4630 | 3700 | .181 | 4510 | 3892 | .137 | 4755 | 3915 | .133 |
| 11 | None | 1447 | ---- | 667 | ---- | .095 | 991 | ---- | .103 | 721 | ---- | .077 | 865 | ---- | ---- |

* Yields expressed in pounds per acre.

Fig. 4. Average yield of clover, 1930-40, yield of series B, 1939 and 1940, and percent sulphur for 1939 and 1940.



Average yield 1930-40, yield for 1939 and percent sulphur of clovers grown on series G and A at Breton

Fig. 5 . Series G, 1939.

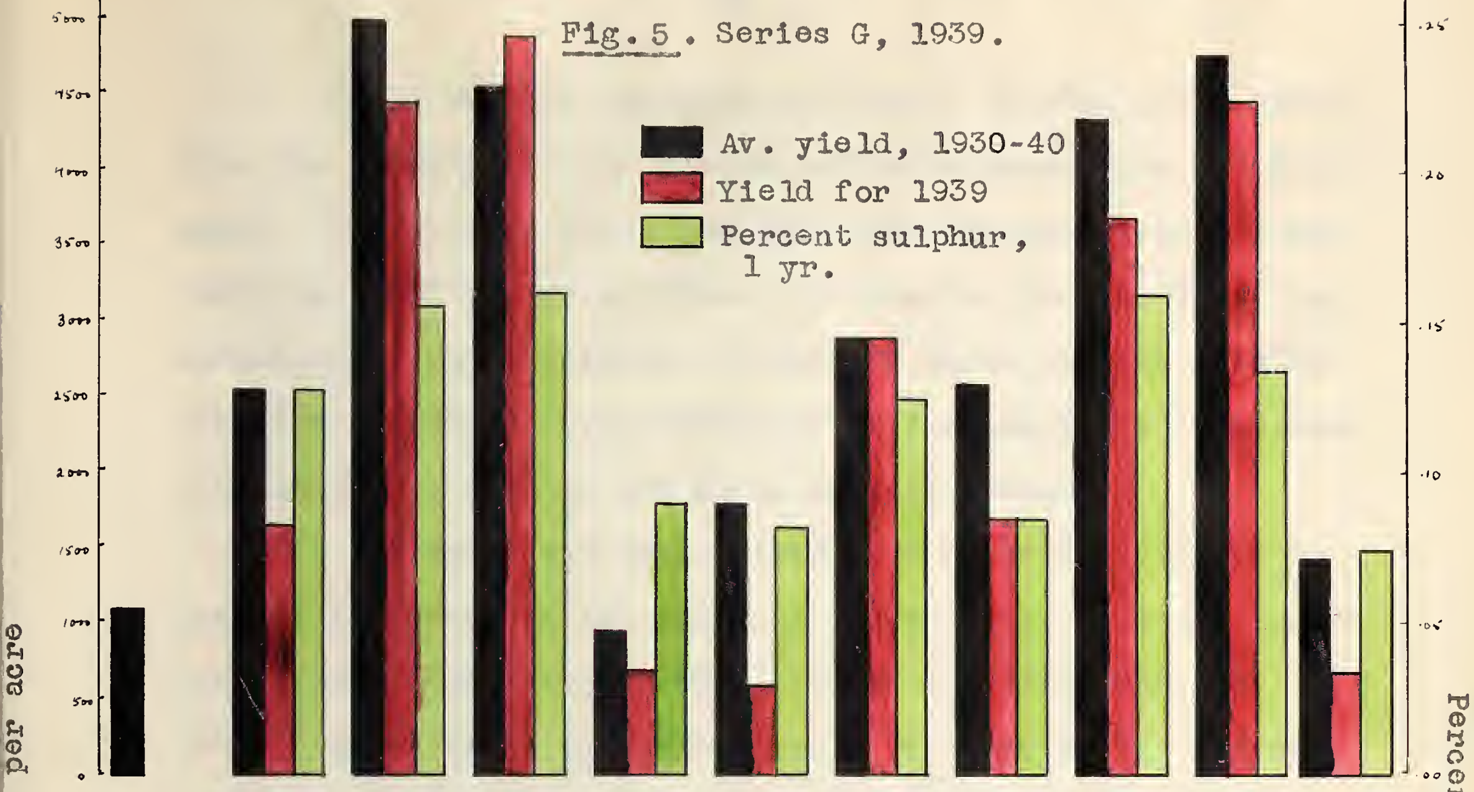
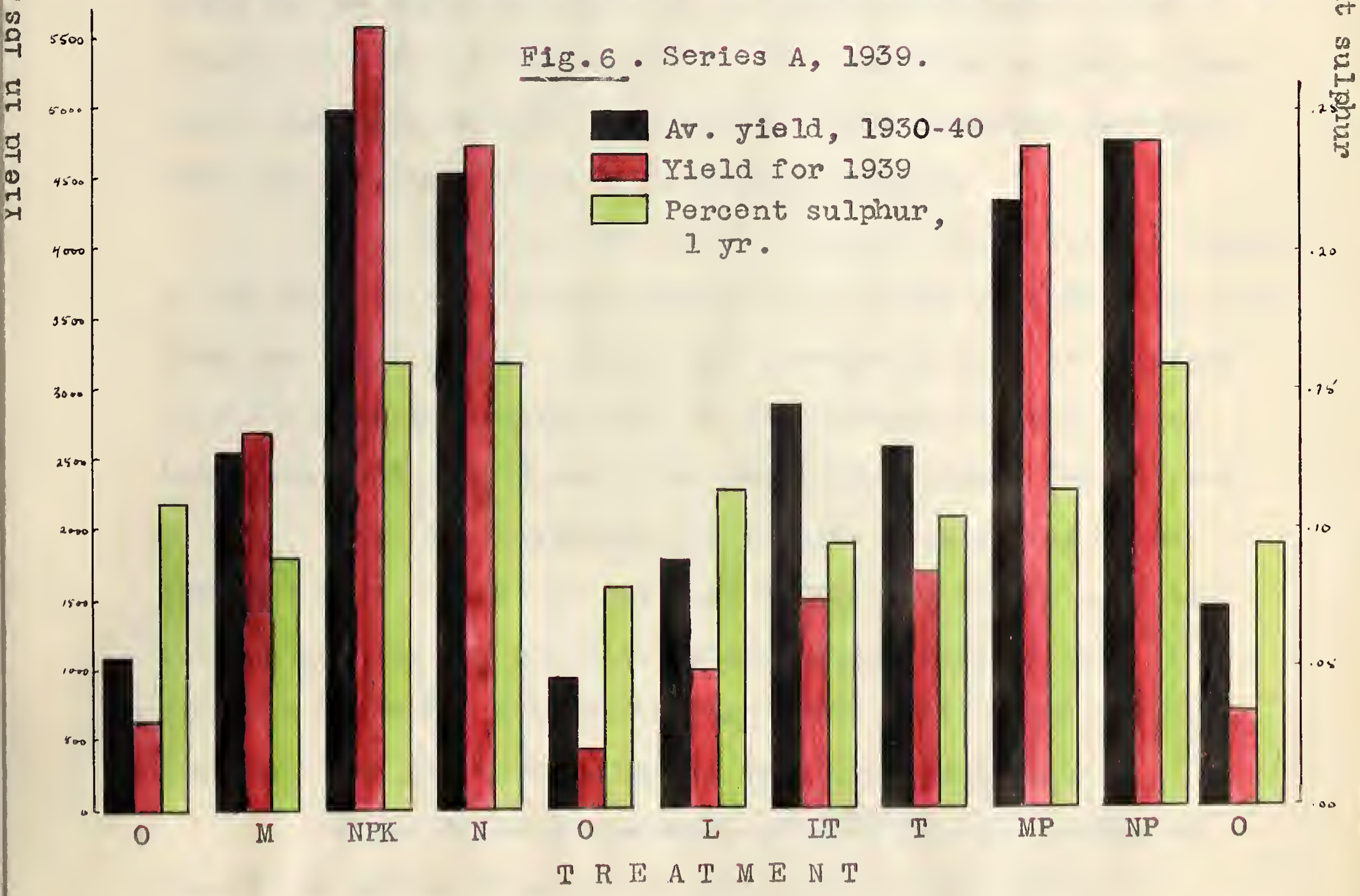
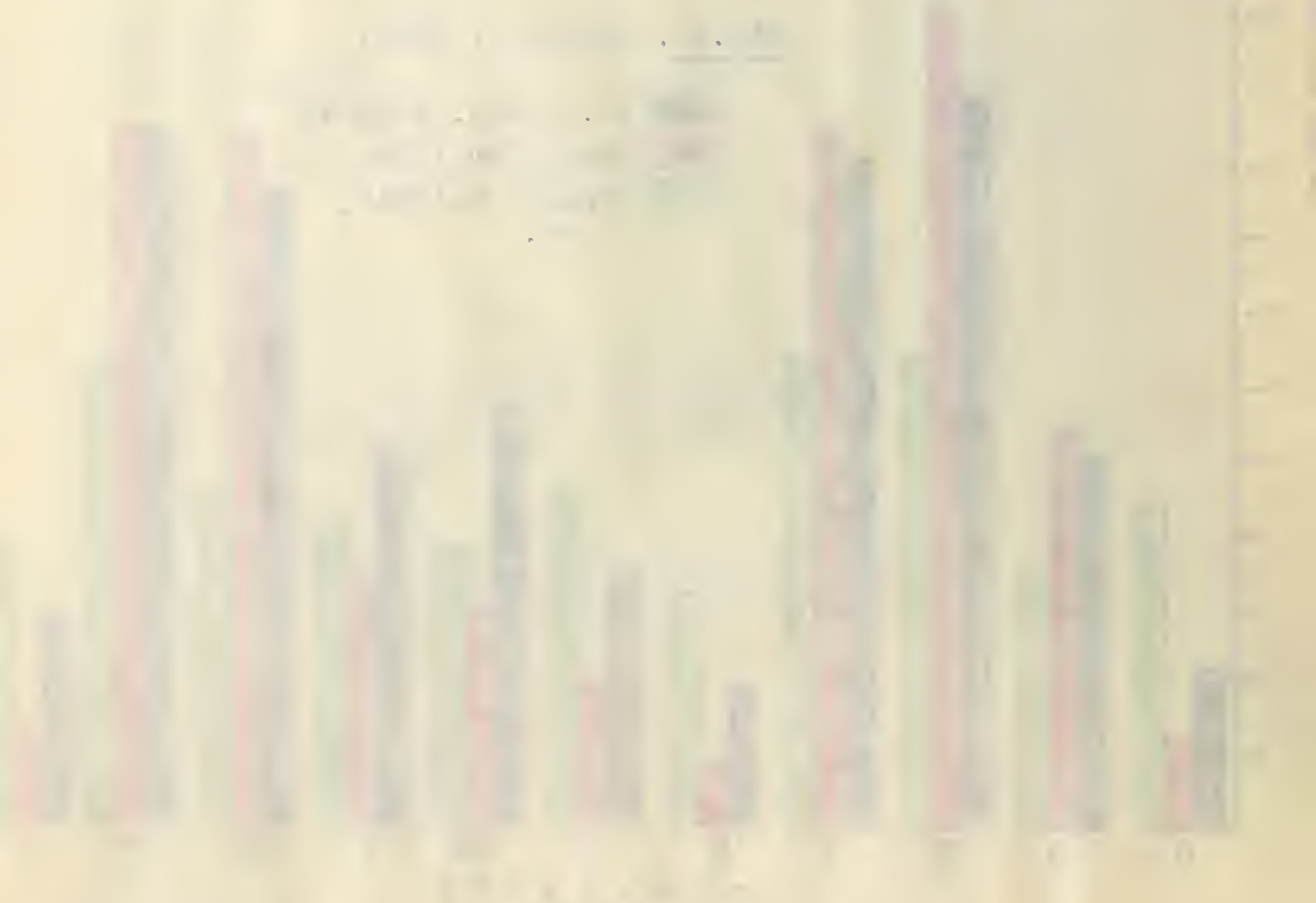


Fig. 6 . Series A, 1939.





The results reported in Table 8 and Fig. 4, 5 and 6, give the percent sulphur content of the clovers from the Breton plots. The average yield for 1930-1940 and the yield for the years analyzed are given also. The results for the first and second years in succession on series B plots and the results from the second year of clovers grown for two years in succession on series A and G are given in this table.

As Wyatt and Newton (28) have reported that the greater increases in the yield of legumes were obtained from fertilizers containing sulphur, it was expected that the greater percentages of sulphur would be found in the legumes grown on the plots treated with sulphur fertilizers. The results in Table 8 bear this out. The ammonium sulphate, complete, ammonium phosphate, and manure plus ammonium phosphate gave the greatest increases in sulphur content.

The yields of the plots receiving these sulphur fertilizers were on the average four to five times greater than those from the check plots. All of the treatments gave an increase in yield with the application of fertilizers but the larger increases were from those plots receiving sulphur fertilizers.

Fig. 4 illustrates the results from series B for 1939 and 1940. There is not much difference in the percent sulphur content for these two years except perhaps that it is slightly lower for the second year. The yield drops slightly also but this is probably due to seasonal variation.

Figs. 5 and 6 represent graphically the yields of clovers on series G and F for 1939, the average yield for

1930-1940 and the percent sulphur content of clover for 1939. This is the percent sulphur for the second year of legumes grown two years in succession. The percent sulphur content of the corresponding plots on both series is more or less alike, also the yields correspond very closely to the average yield. As stated before, the greater increases in yield and percent sulphur are obtained from those plots receiving the sulphur fertilizers.

Table 9. The sulphur content and yield of barley grown on Breton fertilizer plots, 1940 and 1941

| | | | | Series D, 1940 | | | Series F, 1941 | | |
|---|---|---|---|---|---|---|---|---|---|
| Plot | Treatment | Av. yield 1930 - 40 | Av. incr. | Yield | Incr. | % S | Yield | Incr. | % S |
| 1 | None | 12.9 | ---- | 15.4 | ---- | .055 | 16.4 | ---- | .085 |
| 2 | Manure | 20.0 | 7.0 | 32.8 | 17.5 | .091 | 19.4 | 4.8 | .110 |
| 3 | Complete | 22.1 | 9.2 | 31.1 | 15.8 | .104 | 21.2 | 8.4 | .139 |
| 4 | Ammon. sulphate | 23.3 | 10.3 | 32.5 | 17.3 | .117 | 23.0 | 12.0 | .147 |
| 5 | None | 13.0 | ---- | 15.2 | ---- | .070 | 9.2 | ---- | .096 |
| 6 | Lime | 15.4 | 1.8 | 15.4 | -0.8 | .110 | 11.3 | 1.7 | .102 |
| 7 | Lime + triple | 18.0 | 3.8 | 24.4 | 7.8 | .113 | 13.9 | 3.8 | .121 |
| 8 | Triple | 16.3 | 1.5 | 20.4 | 3.1 | .111 | 13.9 | 3.4 | .114 |
| 9 | Manure + phosphate | 25.0 | 10.5 | 49.7 | 31.7 | .124 | 29.6 | 18.6 | .144 |
| 10 | 16-20 | 24.5 | 8.5 | 36.5 | 17.8 | .131 | 25.0 | 13.6 | .147 |
| 11 | None | 16.7 | ---- | 19.5 | ---- | .089 | 11.9 | ---- | .116 |

Average yields 1930-40, yield for 1940 and 1941, and percent sulphur of barley grown at Breton

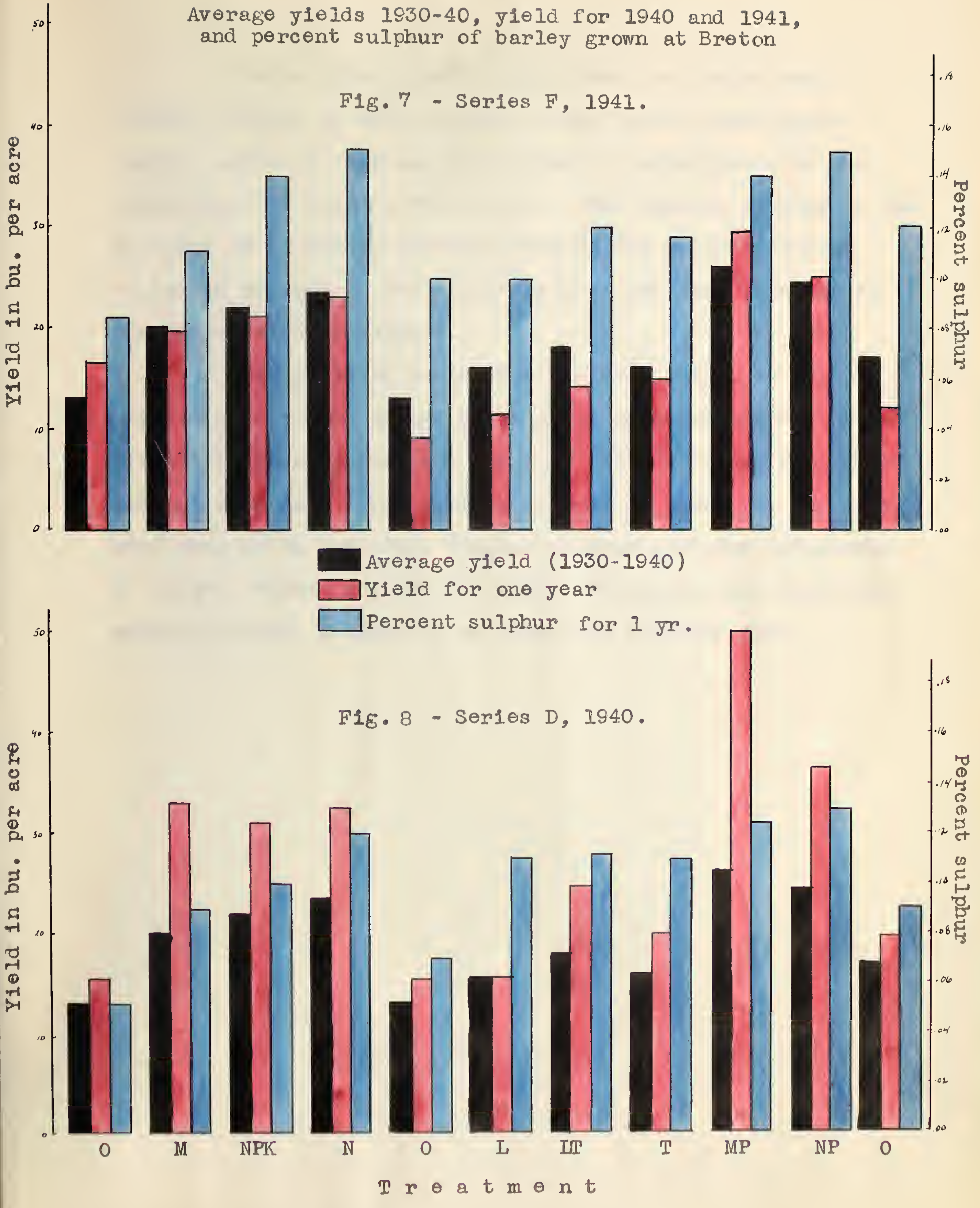


Fig. 7 - Series F, 1941.

Fig. 8 - Series D, 1940.

Table 9 and Figs. 7 and 8 show the yields and sulphur content of barley grown on the Breton fertilizer plots. Again an increase in sulphur is correlated with the application of sulphur fertilizers. The percent sulphur is not as great as in wheat, probably because the protein content of barley is lower. The yields fall in the same order as do the percentages of sulphur.

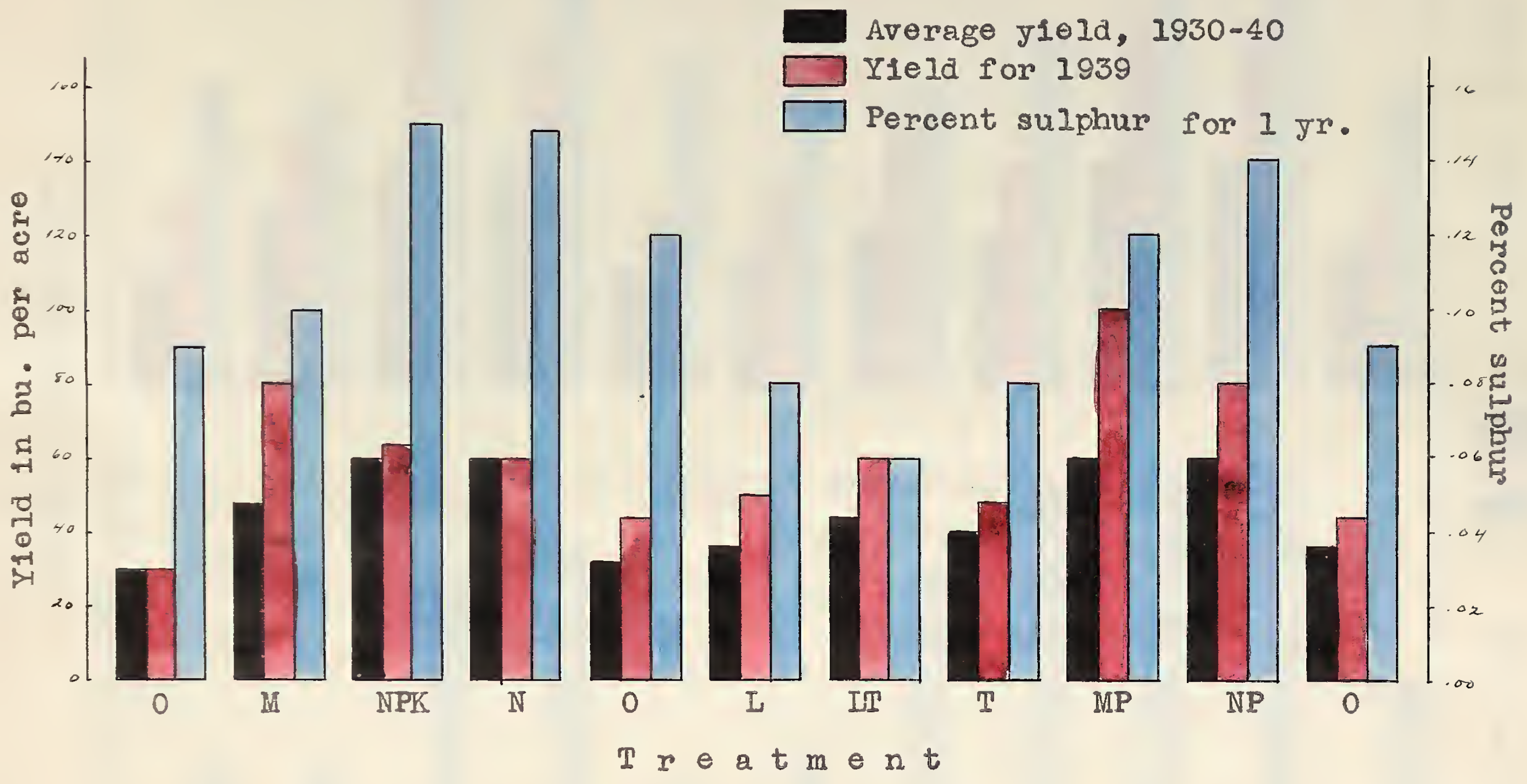
The yield of barley for series F, 1941, is about average whereas for series D, 1940, it is above average. The percent sulphur content for the year 1941 is higher than that for the year 1940. The protein content is lower for the year 1940 than it is for 1941, falling in line with the percentage of sulphur which is lower for 1940. The graph also shows the percent sulphur content to be lower for the year 1940.

Table 10. The sulphur content and yield of oats grown on Breton fertilizer plots

| Plot | Treatment | Av. yield 1930-40 | Av. incr. | Series A West half, 1941 |  |  | Series F West half, 1940 |  |  | Series D West half, 1939 |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | Yield | Incr. | % S | Yield | Incr. | % S | Yield | Incr. | % S |
| 1 | None | 29.5 | ---- | 17.3 | ---- | .076 | 46.3 | ---- | .081 | 27.2 | ---- | .092 |
| 2 | Manure | 48.0 | 17.8 | 50.0 | 30.0 | .080 | 68.2 | 21.8 | .081 | 81.6 | 50.2 | .104 |
| 3 | Complete | 58.4 | 27.4 | 47.1 | 24.4 | .129 | 127.2 | 80.7 | .140 | 65.5 | 29.5 | .146 |
| 4 | Ammon. sulphate | 60.6 | 28.9 | 44.9 | 19.5 | .142 | 92.8 | 46.2 | .157 | 63.7 | 23.3 | .153 |
| 5 | None | 32.5 | ---- | 28.2 | ---- | .070 | 46.8 | ---- | .087 | 44.9 | ---- | .122 |
| 6 | Lime | 36.9 | 3.6 | 31.9 | 3.5 | .085 | 55.0 | 7.8 | .081 | 50.2 | 5.2 | .087 |
| 7 | Lime + triple | 45.3 | 11.1 | 31.2 | 2.6 | .129 | 69.0 | 21.4 | .080 | 63.3 | 18.2 | .063 |
| 8 | Triple | 41.5 | 6.5 | 26.2 | -2.6 | .147 | 58.0 | 9.9 | .095 | 47.3 | 2.1 | .084 |
| 9 | Manure + phosphate | 58.0 | 22.1 | 53.0 | 24.0 | .157 | 98.4 | 49.9 | .114 | 99.9 | 54.6 | .122 |
| 10 | 16-20 | 59.9 | 23.2 | 48.8 | 19.6 | .156 | 96.9 | 48.0 | .144 | 80.2 | 34.8 | .142 |
| 11 | None | 37.6 | ---- | 29.4 | ---- | .099 | 49.4 | ---- | .082 | 45.6 | ---- | .091 |

Fig. 9. Average yield 1930-40, yield for 1939, and percent sulphur of oats grown at Breton

Series D, 1939



Average yield 1930-40, yield for 1940 and 1941, and percent sulphur of oats grown at Breton

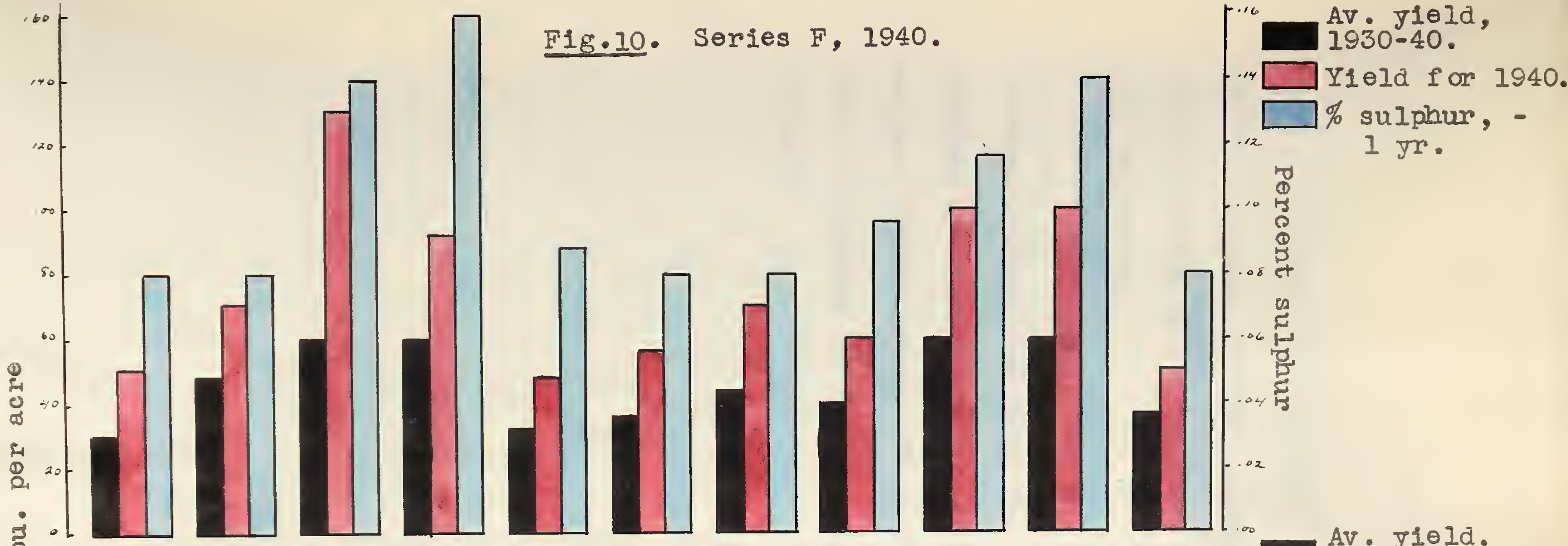


Fig.10. Series F, 1940.

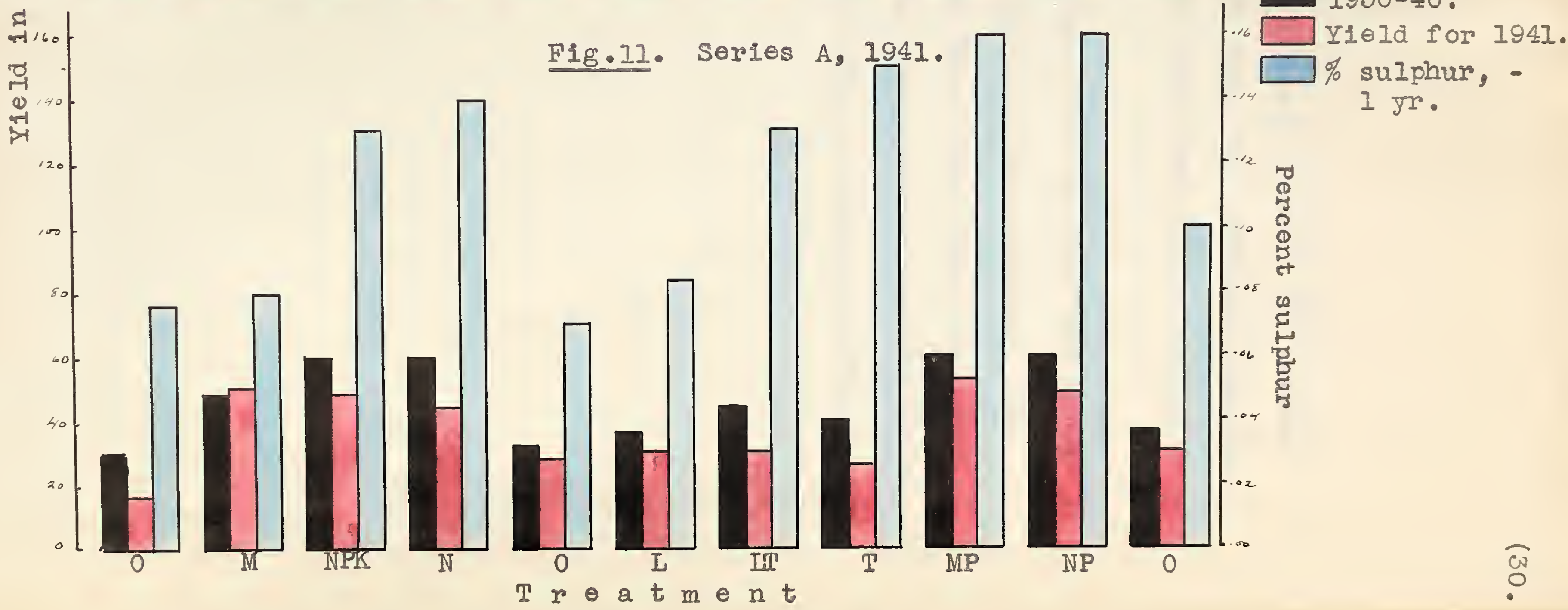


Fig.11. Series A, 1941.

Table 10 and Figs. 9, 10 and 11 give the percent sulphur content and the average yield for 1930-1940 and the yield for the years analyzed of oats grown on the wooded soil at Breton.

The yields for the years 1939 and 1940 are above average whereas for 1941 the yield is below average. The greater increases were obtained from those plots receiving sulphur fertilizers. There does not appear to be any very close correlation of percent sulphur content with the yield in these series of oats.

Table 11. The average yield for 1931-1940, and the yield, sulphur content and protein content of wheat grown on the Soils Farm Experimental Plots in 1940 and 1941*

| Plot | Treatment | Av. yield 1931-40 | Av. incr. | Series C, 1940 | | | | Series A, 1941 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Yield | Incr. | % S | **% P | Yield | Incr. | % S | % P |
| 1 | None | 33.5 | ---- | 53.5 | ---- | .173 | 10.7 | 25.8 | ---- | .183 | 12.5 |
| 2 | Ammon. sulphate | 34.8 | .50 | 51.4 | 1.3 | .184 | 11.9 | 26.0 | 0.2 | .207 | 13.6 |
| 3 | Triple super | 37.8 | 4.50 | 49.7 | 3.0 | .157 | 9.2 | 27.8 | 1.9 | .183 | 13.6 |
| 4 | 11-48 | 38.4 | 4.17 | 46.6 | 3.3 | .201 | 8.9 | 27.0 | 1.1 | .187 | 13.4 |
| 5 | Complete | 39.9 | 7.78 | 58.5 | 18.6 | .146 | 8.9 | 30.6 | 4.6 | .198 | 13.1 |
| 6 & 7 | None | 33.3 | ---- | 33.2 | ---- | .148 | 8.1 | 26.6 | ---- | .188 | 13.7 |
| 8 | Ammon. sulphate | 34.0 | 2.94 | 50.9 | 15.4 | .170 | 10.7 | 26.1 | -1.4 | .187 | 13.6 |
| 9 | Triple super | 37.4 | 6.95 | 52.2 | 14.4 | .147 | 8.7 | 34.3 | 6.4 | .158 | 12.9 |
| 10 | 11-48 | 36.4 | 4.69 | 43.6 | 3.5 | .146 | 9.5 | 35.1 | 6.8 | .209 | 13.2 |
| 11 | Complete | 40.1 | 7.51 | 51.8 | 9.4 | .168 | 9.4 | 34.6 | 5.9 | .199 | 13.0 |
| 12 | None | 32.3 | ---- | 47.1 | ---- | .174 | 11.2 | 26.5 | ---- | .188 | 13.2 |

Note: Average yield of all checks 1931-1940 is 33.04 bushels per acre.

* Yields expressed in bushels per acre.

**Percent protein obtained from Soils Department records.

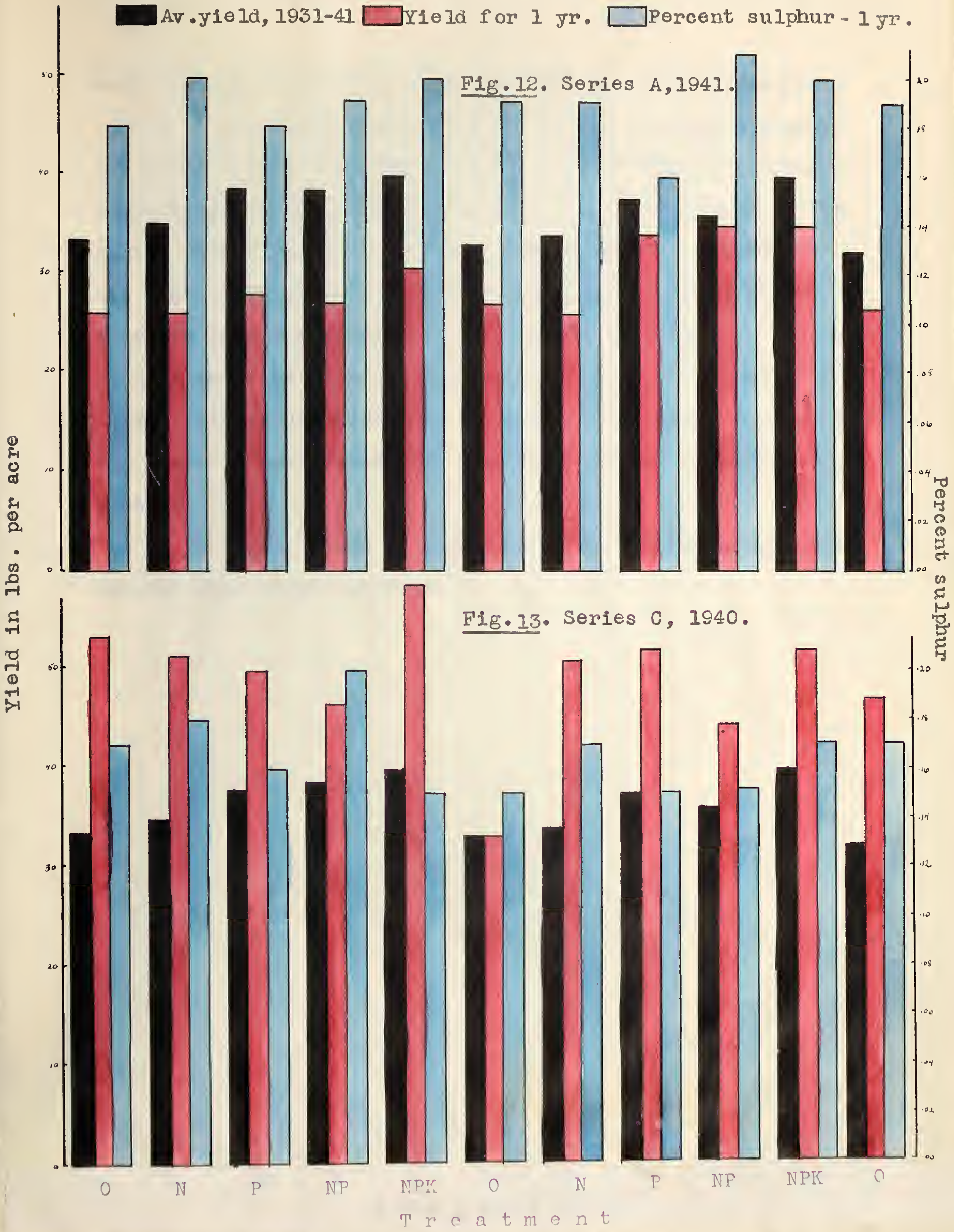
Table 12. The average sulphur content of wheat from the Soils Department experimental plots for the various treatments

| Treatment | Percent sulphur |
|---|---|
| None | .176 |
| Ammonium sulphate | .187 |
| Triple super | .161 |
| Ammonium phosphate (11-48) | .186 |
| Complete | .176 |

The fertility of the plots on the Soils Experimental Farm at the University of Alberta is high as shown by the average wheat yield of 33.0 bushels on the check plots. Ammonium sulphate alone is of no value in these experiments as the average increase in yield is negligible. The plots receiving triple superphosphate, ammonium phosphate (11-48) and complete fertilizers, all containing phosphorus, showed substantial increases in average yield over the checks.

Table 11 shows that for 1941 the yield was low as compared to the average yield, and that for 1940 the yield was higher than average. The percentage of sulphur and protein in the wheat from almost all plots was relatively high for the year with the lower than average wheat yield. From this it would appear that the larger the yield of grain the lower generally is the sulphur and protein content. As sulphur is an essential constituent of most of the proteins it might follow that

Fig.12,13. Average yield 1931-41, yield for 1941 and 1940, and percent sulphur of wheat grown at Soils Farm, Edmonton



the lower the protein content the lower the sulphur content.

If sulphur were a limiting factor on these plots, one could assume that the application of sulphur fertilizers would increase the yield and also the sulphur content of the grain. Table 12 shows that the average percent sulphur of the wheat from the fertilized plots showed no significant increase from the application of sulphur fertilizers. These results indicate that sulphur is not a limiting factor in the black soils around Edmonton, also that the sulphur content of the grain is correlated with the yield and the percentage protein.

Figs. 12 and 13 represent these results graphically for the years 1941 and 1940.

Table 13. The percent sulphur of surface 6 2/3 inches of gray wooded soils from Breton after clovers and after fallow

| | | Series C, E. ½ | Series E, W.½ |
|---|---|---|---|
| Plot | Treatment | Rotation includes clovers. Plowed down, fall 1941. % S | Continuous wheat series. Fallowed 1941. % S |
| 1 | None | .010 | .006 |
| 2 | Manure | .026 | .009 |
| 3 | Complete | .025 | .008 |
| 4 | Ammon. sulphate | .025 | .009 |
| 5 | None | .018 | .010 |
| 6 | Lime | .017 | .009 |
| 7 | Lime + triple | .010 | .009 |
| 8 | Triple superphosphate | .010 | .009 |
| 9 | Manure + phosphate | .018 | .0027 |
| 10 | Ammonium phosphate (16-20) | .021 | .013 |
| 11 | None | .015 | .012 |

Edmonton black cultivated: .076% sulphur.

" " virgin: .104% " .

Table 13 shows the low total sulphur content of the unfertilized and fertilized gray wooded soils. The unfertilized Edmonton black soil has a high percentage of total sulphur when compared to the gray wooded soil. The soil from the Breton, series C rotation plots, containing clovers, shows a slightly higher percentage of total sulphur near the surface than the soil from series E plots which have had continuous wheat.

There are indications that the sulphur content of the soil from the sulphur fertilized plots contains more total sulphur than that of plots receiving no treatment; however, more work will have to be done before any very definite statement can be made in this respect.

## DISCUSSION

The wooded soils are deficient in sulphur and applications of sulphur fertilizers are necessary to make available to the plant sufficient sulphur for its needs. It is apparent that more importance will have to be attached to the inclusion of sulphur fertilizers in the rotation on the wooded soils if satisfactory yields are to be obtained. Legumes benefit greatly by the application of sulphur fertilizers and since they are a necessary part of the rotation the importance of sulphur cannot be over-emphasized in this respect; otherwise the yields of clovers at Breton are very low. Legumes fix nitrogen so that any fertilizer or element which increases the yield of legumes increases also the nitrogen and organic matter content of the soil, especially when the legumes are plowed under.

The lack of organic matter and the greater leaching that has taken place in the gray wooded soils probably accounts for their lack of sulphur. Sulphates are readily leached out of the soil. There is a definite trend towards a higher sulphur content in the surface soil where clovers have been grown. This is probably due to the legumes removing the sulphates from the lower horizons of the soil and utilizing them in growth. This would account for the higher sulphur content, especially where the legumes are plowed down. No trace of water soluble sulphates could be found on the series of surface soil on which

total sulphur was determined.

No work has been done to determine the sulphur that is available to the plant and its relation to the sulphur content of the soil. The available sulphur in the soil may be much less than the total sulphur and many soils which now contain a fairly high percent of sulphur may become deficient in available sulphur even though the total sulphur content is reasonably high. Sulphur usually exists in the soil in the form of sulphates, in organic combination, and as sulphides.

Wyatt and Newton (28) show that the protein content of wheat after clovers is higher than that of wheat grown continuously. The sulphur content of the two series analyzed was quite similar. Wyatt and Newton also state that the protein quality is higher for the wheat after clovers than for the continuous wheat.

The highest percentage of sulphur found in the wheat grown at Breton on plots treated with sulphur fertilizers is comparable to the percent sulphur content of the wheat grown on the untreated black soil at Edmonton. No attempt has been made to determine what the maximum increase in sulphur content of wheat would be from heavier applications of sulphur fertilizers. On the black soil at Edmonton the application of sulphur fertilizers did not increase the sulphur content of the wheat so it appears that the wheat is not suffering from a lack of sulphur.

From the results reported there does not seem to be any close relation between the nitrogen content of the wheat

and the sulphur content. The plots that received the most nitrogen also received the most sulphur. The proportion of sulphur to nitrogen is higher in the wheat from the plots treated with sulphur fertilizers.

## SUMMARY

Wheat, oats, barley and legumes, grown on the fertilized plots at Breton, and wheat grown on the black soil were analyzed.

The percent sulphur content of the grains from plots treated with sulphur fertilizers such as complete fertilizer, ammonium sulphate, manure plus ammonium phosphate (16-20), and ammonium phosphate (16-20) was greater than from plots treated with manure, lime, lime plus triple superphosphate, or triple superphosphate.

The ratio of sulphur to nitrogen was higher in the wheat from the plots treated with sulphur fertilizers.

The yield of grain and hay was also increased considerably over those plots not receiving sulphur fertilizers.

Legumes showed the greatest increase in yield from the application of sulphur fertilizers.

There was no increase in the sulphur content of the wheat from the sulphur treated plots on the black soil at Edmonton.

Analyses of the gray wooded and black soils showed

that the gray soils are deficient in total sulphur as compared to the black soil at Edmonton.

The surface soil from the plots in a rotation which included clover had a higher sulphur content than the surface soil from the continuous wheat series.

An attempt was made to determine water soluble sulphates but no measurable amounts were found.

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